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Midfoot osteoarthritis: potential phenotypes and their associations with demographic, symptomatic and clinical characteristics

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ABSTRACT

Objective

To investigate the demographic, symptomatic, clinical and structural foot characteristics associated with potential phenotypes of midfoot osteoarthritis (OA).

Design

Cross-sectional study of 533 community-dwelling adults aged ≥ 50 years with foot pain in the past year. Health questionnaires and clinical assessments of symptoms, foot structure and function were undertaken. Potential midfoot OA phenotypes were defined by the pattern of radiographic joint involvement affecting either the medial midfoot (talonavicular, navicular-1st cuneiform, or cuneiform-1st metatarsal joint), central midfoot (2nd cuneiform-metatarsal joint), or both medial and central midfoot joints. Multivariable regression models with generalised estimating equations were used to investigate the associations between patterns of midfoot joint involvement and symptomatic, clinical and structural characteristics compared to those with no or minimal midfoot OA.

Results

Of 879 eligible feet, 168 had medial midfoot OA, 103 central midfoot OA, 76 both medial and central midfoot OA and 532 no/minimal OA. Having both medial and central midfoot OA was associated with higher pain scores, dorsally-located midfoot pain (OR 2.54, 95%CI 1.45, 4.45), hallux valgus (OR 1.76, 95%CI 1.02, 3.05), flatter foot posture (β 0.44, 95%CI 0.12, 0.77), lower medial arch height (β 0.02, 95%CI 0.01, 0.03) and less subtalar inversion and 1st MTPJ dorsiflexion. Isolated medial midfoot OA and central midfoot OA had few distinguishing clinical characteristics.

Conclusions

Distinct phenotypes of midfoot OA appear challenging to identify, with substantial overlap in symptoms and clinical characteristics. Phenotypic differences in symptoms, foot posture and function were apparent in this study only when both the medial and central midfoot were involved.

Keywords: foot, osteoarthritis, phenotype, midfoot, pain, function

INTRODUCTION

Foot osteoarthritis (OA) is increasingly recognised as an important contributor to the burden of OA, affecting 1 in 6 adults aged over 50 years, with a significant negative impact on physical mobility and quality of life[1-3]. The most commonly affected foot joint is the first metatarsophalangeal (1st MTP; 7.8%), followed by the midfoot, including the second cuneiform-metatarsal (2nd CMJ; 6.8%), talonavicular (TNJ; 5.8%), navicular-first cuneiform (NCJ; 5.2%) and first cuneiform-metatarsal joints (1st CMJ; 3.9%)[1].

Midfoot OA has been recognised as a distinct subtype of foot OA, with recent findings indicating the presence of two main phenotypes of radiographic foot OA based on the pattern of joint involvement[4]. The first is isolated 1st MTPJ OA with minimal midfoot involvement, and the second is polyarticular OA affecting both the 1st MTPJ and midfoot joints (TNJ, NCJ and CMJs). Polyarticular foot OA is the most disabling form of foot OA[4] and is associated with foot pain, obesity, previous injury, lower medial arch height and pain in other weight-bearing joints[2, 4, 5]. The significant impact that midfoot OA has on physical function is, in part, attributed to the important role the midfoot has in distributing load in the foot during weight-bearing activities such as walking[6], standing[7] and stair climbing[8]. Progression towards significant flat-foot deformity with advanced midfoot OA also results in complaints of unusual foot posture and difficulty with footwear fitting[9].

Because the midfoot has a complex structure with many articulations, it is possible that distinct patterns of involvement exist. Indeed, results from a data-driven approach used to identify subgroups of foot OA from a large, population-based cohort identified two main clusters of foot OA (polyarticular and 1st MTPJ), and raised the possibility of two subsets of midfoot OA existing; one affecting the medial midfoot joints only (TNJ, NCJ or 1st CMJ) and the other the central midfoot only or 'second ray' (2nd CMJ)[4].

The potential presence of two subgroups of midfoot OA may be explained, in part, by differences in the function of the medial versus central joints of the midfoot. The most medial part of the midfoot, involving the joints along the medial arch such as the TNJ, 1st NCJ, and 1st CMJ (first ray), is highly mobile during walking and becomes loaded dorsally when the arch flattens[6]. This is in contrast to the 2nd CMJ which contributes less to medial arch stability, is tightly bound, and displays minimal motion[7, 10]. Anatomically, the 1st CMJ and 2nd CMJ also typically have separate synovial compartments[11, 12] further reinforcing their distinction as separate functional entities in the medial and central regions of the midfoot. It is therefore plausible that the mechanisms underlying the development of these two subgroups of midfoot OA differ, which may be reflected in the clinical and structural foot characteristics observed in clinical practice. Existing studies have not been able to adequately investigate patterns of OA within the midfoot and their associations with clinical features due to a focus on either the tarsometatarsal or medial midfoot joints, small sample sizes or a narrow range of measured clinical characteristics[8, 13-17]. There have been no prior studies investigating potential phenotypes specifically in the midfoot, nor any association with clinical characteristics.

Characterising midfoot OA and potential phenotypes in greater detail will improve our understanding of their clinical presentation and may offer early insights into the mechanisms involved in disease pathogenesis. This line of research is also attractive as a basis for developing targeted or stratified interventions for different types of foot OA in the future, two areas identified as key OA research priorities by the European League Against Rheumatism (EULAR)[18]. The aim of this study was to investigate the demographic, symptomatic, clinical and structural foot characteristics associated with potential phenotypes of midfoot OA based on different patterns of joint involvement; medial midfoot OA only (TNJ, NCJ or 1st CMJ), central midfoot OA only (2nd CMJ) and combined medial and central midfoot OA.

METHODS

Study design and population

This study was a cross-sectional analysis of baseline data from the Clinical Assessment Study of the Foot (CASF), a large prospective observational cohort study in North Staffordshire, UK[19]. Health Survey questionnaires were mailed to patients aged 50 years and over registered with four general practices. Individuals who responded and indicated they had foot pain in the last 12 months were invited to attend a research clinic for a clinical assessment and plain radiography of both feet. Participants were excluded from the current analyses if their medical records or radiology report identified them as having inflammatory arthritis (rheumatoid arthritis, psoriatic arthritis or non-specific inflammatory arthritis). All participants provided written informed consent and ethical approval was granted for this study from Coventry Research Ethics Committee (REC reference number: 10/H1210/5).

Data Collection

Health Survey Questionnaire

The Health Survey questionnaire included items on demographics and socio-economic status (age, sex, education, occupation), general health, foot pain and symptoms (pain in the last 12 months, pain severity in the last month using a 0-10 numerical rating scale [NRS], duration of pain, and the Manchester Foot Pain and Disability Index (MFPDI)[20]). Foot pain location was recorded by participants marking or shading the corresponding area on a foot manikin[21, 22] (© The University of Manchester 2000, all rights reserved). Dorsal and plantar midfoot pain were then determined according to the region(s) selected. Raw MFPDI pain and function scores were converted to Rasch-transformed logit values for statistical analysis[23]. The presence of hallux valgus was determined from validated self-report line drawings obtained during the questionnaire[24], with the three most severe depictions graded as present and the two least severe as absent[25].

Clinical assessment

Physical and clinical assessments (foot posture, range-of-motion and deformity) were undertaken on all participants who attended the research clinic according to standardised protocols by one of seven trained therapists (podiatrist or physiotherapist)[19]. Pre-study training and quality control measures were undertaken throughout the study[19]. Anthropometric measurements (height and weight) were taken, and body mass index (BMI) subsequently derived. Foot posture was assessed with participants in a relaxed standing position using the Foot Posture Index (FPI)[26], Arch Index (AI)[27] and Navicular Height (NH), with NH being normalised to the total foot length[28]. The FPI is a six-item observational rating tool for the assessment of overall foot posture, with each item corresponding to an individual feature and graded from -2 (supinated) to +2 (pronated) for maximum scores ranging from -12 (highly supinated) to +12 (highly pronated)[26]. Raw scores were converted to Rasch-transformed logit values for statistical analysis[29]. The AI was derived from carbon paper footprints and is defined as the ratio of the area of the middle third of the foot to the total footprint area (minus the toes)[27]. Higher AI values indicate a more flattened medial foot arch. Measurement of NH was taken by marking the navicular tuberosity with a pen, measuring its height from the supporting surface with a ruler (in millimetres), and dividing this value by the total length of the foot. Lower NH values indicate a flatter medial foot arch[28]. Values for the FPI and AI were also presented in categories based on established cut-points[30, 31], with NH values categorised in tertiles according to the variable distribution.

Range-of-motion at the ankle joint was assessed with an inclinometer using the weight bearing lunge test with the knee flexed and extended[32, 33]. Subtalar/ankle inversion and eversion were assessed with the participant non-weight-bearing using a goniometer[34]. Non-weight bearing dorsiflexion range-of-motion of the 1st MTPJ was also assessed using a flexible goniometer[35]. Midfoot exostosis was documented as the presence or absence of a bony prominence on the dorsum of the foot in non-weight bearing. Reliability of foot posture and clinical tests has previously been reported[28, 32-35].

Radiographic assessment and scoring

Participants had weight-bearing dorsoplantar and lateral radiographs of both feet taken according to a standardised protocol[36]. Radiographs were graded separately for joint space narrowing (JSN) and osteophytes (OP) in four midfoot joints (TNJ, NCJ, 1st CMJ and 2nd CMJ) and the 1st MTPJ by a single reader (M.M.). Radiographic OA of a foot joint was defined as grade ≥2 for osteophytes (OP) or joint space narrowing (JSN) on either dorsoplantar or lateral views, as previously described [36]. Intra- and inter-observer reliability (MM and HBM) for scoring within this dataset have previously been reported as excellent (mean unweighted κ = 0.94, mean % agreement 99%) and moderate (mean unweighted κ = 0.46, mean % agreement 79%), respectively[1].

Four mutually exclusive groups were defined according to the presence of radiographic OA in the midfoot joints of each foot (Figure 1):

(1) Medial midfoot OA only: grade ≥2 for JSN or OP in either the TNJ or NCJ or 1^{st} CMJ, with no OA (grade ≤1) in the 2^{nd} CMJ.
(2) Central midfoot OA only: grade ≥2 for JSN or OP in the 2^{nd} CMJ only, with no OA (grade ≤1) in the TNJ, NCJ and 1^{st} CMJ.
(3) Combined medial and central midfoot OA: grade ≥ 2 for JSN or OP in both the medial midfoot (at least one of the TNJ, NCJ or 1^{st} CMJ) and central midfoot (2^{nd} CMJ). This group was included to ensure feet with OA involvement across both regions were included, as we anticipated a significant number of feet with more extensive involvement.
(4) No or minimal OA: No OA of the midfoot (grade ≤1) for JSN or OP for the TNJ, NCJ, 1st CMJ and 2^{nd} CMJ.

Figure 1 here

Statistical analysis

Differences between midfoot OA phenotypes were assessed using multivariable linear regression for continuous outcomes and binary logistic regression for dichotomous outcomes. All necessary assumptions for the analyses were tested for and met. Analyses were foot-based, with generalised estimating equations used to account for between foot correlations within each person and adjusted for age, sex and BMI. Further adjustment was also made for the presence of 1^{st} MTPJ OA. An exchangeable working correlation structure was specified for the analysis given the lack of time-dependent or logical ordering of the data. The no or minimal OA group were designated as the reference category. Results for continuous outcomes are presented as adjusted unstandardised regression coefficients (β) and considered statistically significant if the 95% confidence intervals (CI) did not include 0. For dichotomous outcomes, results are presented as adjusted odds ratios (ORs) with 95% CI and were considered statistically significant if the 95% CI did not include 1.00. All analyses were conducted using SPSS (v21, IBM Corporation, NY, USA).

RESULTS

Descriptive characteristics

Five hundred and sixty people attended the research assessment clinics, of whom 24 had inflammatory arthritis and three did not have foot radiographs, leaving 533 eligible clinic attenders for analysis (mean age 64.9 years SD [8.4], 55% female).

Of the 1066 feet, 532 had no or minimal OA of the midfoot (49.9%), 168 had medial midfoot OA only (15.7%), 103 had central midfoot OA only (9.6%), and 76 had combined medial and central midfoot OA (7.1%). Isolated OA of the 1st MTPJ occurred in 175 feet and with radiographic data were missing for 12 1st MTP joints (not included in analyses). Compared to the midfoot OA groups, those with isolated 1st MTPJ OA tended to be similar for age, BMI and proportion attending higher education; whilst having a higher proportion in manual occupations and less self-reported foot pain and better foot function (data not shown). The prevalence of concurrent 1st MTPJ OA in feet with midfoot OA was 15% (n=134). In feet with medial midfoot OA, the TNJ was most commonly affected (70%), followed by the NCJ (21%) and 1st CMJ (19%). In feet with medial and central OA, the most common joints with OA were the 2nd CMJ (100%) and NCJ (63%), followed by the TNJ (46%) and 1st CMJ (22%). Twenty of the 879 feet in the analysis (2.2%) had no radiographic changes (0 for OP or JSN).

Summary statistics for person and foot-level characteristics according to the different patterns of midfoot OA involvement are presented in Table 1. Individuals with combined medial and central midfoot OA tended to be older, had a higher BMI, a longer duration of symptoms, a higher proportion with manual occupations and a higher proportion of females compared to the no or minimal midfoot OA group. Those with central midfoot OA only tended to be older, and those with medial midfoot OA only had a higher BMI compared to the no or minimal midfoot OA group.

Table 1 here

Clinical characteristics

Multivariable associations between clinical characteristics and midfoot OA groups adjusted for age, sex, BMI and presence of 1st MTPJ OA are presented in Table 2. For clarity, only fully adjusted models are presented (partially adjusted regression models for age, sex and BMI are also provided in Supplementary File 1 for completeness).

Following adjustment for age, sex, BMI and presence of 1st MTPJ OA, the combined medial and central midfoot OA group was more likely to report dorsally-located midfoot pain (OR 2.54; 95% CI 1.46, 4.44), and hallux valgus (OR 1.76; 95% CI 1.02, 3.05) and had higher MFPDI pain scores indicating worse pain (β = 0.004, 95% CI 0.0000002, 0.008) compared to the no or minimal OA group. They also displayed a flatter foot posture, with higher FPI (β = 0.44; 95% CI 0.12, 0.77) and AI scores (β = 0.02; 95% CI 0.01, 0.03) and lower navicular height (β = -0.01; 95% CI -0.01, -0.002), and had less subtalar inversion (β = -2.45; 95% CI -4.41, -0.48) and 1st MTPJ dorsiflexion (β = -4.30; 95% CI -8.38, -0.21). Differences in pain severity and foot posture were relatively small in magnitude compared to the no or minimal OA group.

Central midfoot OA was associated with higher MFPDI pain scores (β = 0.004; 95% CI 0.0002, 0.008), a higher AI (flatter medial arch) (β = 0.010; 95% CI 0.000002, 0.02) and less ankle joint dorsiflexion (β = -1.464; 95% CI 2.924, -0.005) compared to the no or minimal OA group, with the magnitude of these associations representing small effects. The strength of the association between those with central midfoot OA and the likelihood of reporting dorsal midfoot pain compared to the no or minimal OA group was similar, but less precise, versus the same association for the combined medial and central OA group (OR 1.59; 95% CI 0.95, 2.66, P = 0.078).

Medial midfoot OA was associated with increased likelihood of reporting dorsally located midfoot pain (OR 1.54; 95% CI 1.02, 2.33) and less subtalar inversion (β = -1.715; 95% CI -2.955, -0.474) compared to the no or minimal OA group. The direction of association for ankle joint dorsiflexion and subtalar inversion was opposite for the medial midfoot OA group compared to the central and combined medial and central groups, with greater ankle joint dorsiflexion and less subtalar inversion.

Table 2 here

DISCUSSION

This study aimed to investigate the demographic, symptomatic, clinical and structural foot characteristics associated with different phenotypes of midfoot OA. Previous findings have alluded to different phenotypes based on the pattern of joint involvement affecting either the medial or central regions of the midfoot. We therefore hypothesized that the differences in joint involvement may be reflected in the clinical and structural foot characteristics observed in clinical assessments. Overall, OA affecting both the medial and central midfoot joints was associated with differences in symptoms, foot posture and range-of-motion compared to the no/minimal foot OA group. Overlap in the clinical characteristics of isolated medial or central midfoot OA were observed, making it challenging to differentiate these presentations on the basis of their symptoms and clinical information alone.

Midfoot OA is associated with significant pain-related disability[2, 4], alterations to midfoot alignment[13] and reduced range-of-motion during movement[8]. In this study, high levels of foot pain-related disability were observed in the presence of OA across the combined medial and central midfoot regions, expanding on our previous findings[4]. Pain was more likely to be situated in the dorsal midfoot region, representing a new finding regarding the localisation of pain in people with midfoot OA. This is most likely explained by the close proximity of the midfoot joints to the dorsal aspect of the foot, and aggregation of bony and soft tissue changes near the joint surface[37].

Differences in clinical measures of foot structure such as a flatter medial longitudinal arch were also observed in this study, consistent with studies using radiological measures[13, 38]. Combined with higher maximum forces and pressures under the midfoot during walking in people with midfoot OA[13, 14], these changes may have implications for performing activities that place significant load through the midfoot such as stair climbing[8] and have been shown to relate to levels of pain-related disability[14].

When OA was present in both the medial and central midfoot, individuals tended to be older with a longer duration of symptoms compared to the other patterns of midfoot OA. Changes to overall foot posture indicated by the FPI score and a flatter medial arch were evident with involvement of both the medial and central midfoot joints, whereas this was confined to a flatter medial arch in central midfoot OA. The FPI captures additional elements of foot position during standing such as abduction of the forefoot and eversion of the hindfoot. This suggests the possibility that the effect of midfoot OA on symptoms and foot structure may be cumulative and progressive in nature, with differences observed once midfoot OA is present in both medial and central regions, although prospective studies are needed. It is also possible that this reflects a greater number of midfoot joints involved or greater radiographic severity, although relationships between symptoms and clinical characteristics with the extent of OA and radiographic severity are not always consistent[39]. Recent evidence suggests symptoms of midfoot OA across the medial and central midfoot joints are persistent, with little change over 18 months[40]. Further study is required to determine whether joint involvement and foot structure in midfoot OA changes longitudinally and whether this is related to symptoms.

This study also identified the presence of differences in foot function in people with midfoot OA not previously reported, including less subtalar inversion and 1st MTPJ dorsiflexion, and a higher likelihood of hallux valgus. These associated changes in the feet more generally may imply a wider-reaching impact of midfoot OA on foot function, with potential implications for the management of associated foot deformity. Although evidence from prospective studies is lacking, associations between flat foot posture with 1st MTPJ ROM, OA and hallux valgus have been reported[41-43]. Given that people with midfoot OA have flatter feet than those with no or minimal OA[13, 16], it is possible that the mechanisms involved in the development of forefoot pathology are common to flat feet and midfoot OA. However, the temporal sequence of such proposed events cannot be determined from cross-sectional studies and prospective investigation is required to explore the long-term sequelae of midfoot OA.

Contrary to our hypothesis, limited distinction in the clinical characteristics between patterns of isolated medial and central midfoot OA were observed in this study. Only small differences in range-of-motion at the ankle and subtalar joints were present, with this varying very little (less than two degrees) according to the presence of isolated medial or isolated central midfoot OA. Larger differences were seen for the combined medial and central midfoot OA group, including measures of overall foot posture, arch height, dorsal midfoot pain, presence of hallux valgus, subtalar inversion and 1^{st} MTPJ range-of-motion. Subsequently, identification of more extensive midfoot OA based on these clinical features may be achieved with greater confidence, with consistency of the findings across these outcomes. Although the findings indicated a tendency for greater ankle dorsiflexion and less subtalar inversion for medial midfoot OA, they do not offer any pertinent insights into potential mechanisms of disease pathogenesis for different subsets of midfoot OA. Otherwise, there was considerable overlap in clinical characteristics between feet with midfoot OA in different regions. These findings mirror challenges identified in the identification of potential phenotypes in other regions of small joint OA, such as the hand[44, 45]. Considerable overlap has been identified in symptoms, self-reported function and strength according to the location and distribution of OA[44]. From a practical standpoint, our data suggests that it is difficult to differentiate between isolated medial midfoot OA and isolated central midfoot OA on clinical grounds. The findings of this study also provide insight into clinical features more likely to distinguish combined medial and central midfoot OA, such as a more pronated overall foot posture and reduced navicular height. Therefore at present, in the absence of medical imaging, suspected midfoot OA affecting joints such as the NCJ, 1^{st} CMJ and 2^{nd} CMJ should probably be investigated approaching these joints as a composite unit. It is also possible that phenotypes of midfoot OA based on the pattern of joint involvement may not be detectable in the clinical setting, or that more detailed information is required to identify them. Indeed, brief clinical assessments perform poorly in diagnosing radiographic midfoot OA in individuals with midfoot pain[5], highlighting the additional complexities in distinguishing subsets of midfoot OA. Recent studies of OA phenotyping at other joints with magnetic resonance imaging[46, 47], pain and psychological profiling[48-50] and muscle strength assessment[51] present opportunities that could be applied to midfoot OA in future studies.

Strengths of this study include drawing on a large community-dwelling sample of adults with foot OA and a wide range of documented clinical characteristics relating to symptoms, foot structure and function. Generalised estimating equations were used to maximise the available data from both feet, whilst accounting for between-feet correlations within each person. The assessment items had well established reliability (with the exception of lower inter-rater reliability for ankle/subtalar inversion and eversion) and were reflective of the types of measurements commonly taken in clinical practice. Whilst reliability testing was not performed formally during the study, quality assurance and control were integral parts as detailed in the study protocol[19].

There are also limitations to be considered when interpreting the findings of this study. Midfoot OA subsets were based on the pattern of OA joint involvement in four midfoot joints due to the availability of an established and reliable radiographic atlas for these articulations. Involvement of other midfoot joints is possible and should be explored further in future studies, although reliable scoring of other joints may be problematic. Although there was a large number of total participants with foot OA, the number in each of the subgroups was smaller, reducing statistical power. Participants in this study also experienced foot pain in the past 12 months, therefore caution should be taken extrapolating these findings to the wider population. Despite an array of clinical assessment items being undertaken, items relating to pain at specific joints in the midfoot upon palpation and movement may be more informative, albeit the reliability and clinical utility of other tests is unclear. Lastly, the exploratory nature of this analysis now warrants further investigation to substantiate the clinical significance of differences in characteristics between subsets of midfoot OA.

In conclusion, this is the first detailed investigation exploring potential midfoot OA phenotypes based on the pattern of joint involvement and their associated demographic, symptomatic and clinical characteristics. Midfoot OA affecting both the medial and central joints was associated with higher levels of foot-related pain, most commonly located on the dorsal aspect of the midfoot. This was accompanied by a flatter overall foot posture, lower medial longitudinal arch, less subtalar inversion and 1st MTPJ dorsiflexion. Limited distinguishing clinical characteristics existed between patterns of OA present in the medial or central midfoot, highlighting challenges in the identification of further subsets of midfoot OA in the clinical setting. Differences in alignment of the medial arch may offer potential for distinguishing midfoot OA at different sites and at different stages of disease development. Future studies are warranted to track disease progression and joint involvement in midfoot OA over time and the associated changes in symptoms and functional impairment.

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AUTHOR CONTRIBUTIONS

JBA, MJT, HBM and ER conceived and designed the study. MJT, MM and ER were responsible for data acquisition. Analysis and interpretation of data was undertaken by JBA, MM, MJT, AR, HBM and ER. All authors drafted or revised the article critically for important intellectual content, and approved the final version of the manuscript.

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ROLE OF THE FUNDER

The funder played no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; and preparation, review, or approval of the manuscript or decision to submit the manuscript for publication.

CONFLICT OF INTEREST

The authors have no financial or other competing interests to declare.

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Figure legends

Figure 1. Dorsoplantar radiographs depicting examples of patterns of joint involvement for feet with no or minimal OA (A), medial midfoot OA affecting the NCJ and TNJ (B), central midfoot OA in the 2nd CMJ (C), and combined medial and central midfoot OA affecting the NCJ, 1st and 2nd CMJ (D).

Table 1. Person-level characteristics (age, sex, BMI, pain ratings, MFPDI) and foot-level characteristics for groups (n=879 feet)

	No or minimal foot OA (n=532)	**Medial midfoot OA (n=168)** TNJ or NCJ or 1st CMJ (and no 2nd CMJ)	**Central midfoot OA (n=103)** 2nd CMJ only	**Combined medial and central midfoot OA (n=76)** TNJ or NCJ or 1st CMJ & 2nd CMJ
Age, years	63.7 (63.0, 64.4)	65.6 (64.2, 66.9)	66.9 (65.3, 68.6)	68.3 (66.6, 70.1)
Sex, % female	54.7 (50.5, 58.9)	50.6 (43.0, 58.2)	63.1 (53.8, 72.4)	75.0 (65.3, 84.7)
BMI (kg/m^2)	29.7 (29.3, 30.2)	31.2 (30.3, 32.1)	30.8 (29.8, 31.8)	32.7 (31.3, 34.0)
Manual occupation, %	51.3 (47.1, 55.6)	51.7 (44.2, 59.3)	46.6 (37.0, 56.2)	59.2 (48.2, 70.3)
Attended higher education, %	30.6 (26.0, 33.8)	21.6 (14.2, 26.3)	26.4 (17.7, 34.7)	18.6 (9.7, 27.1)
Joint specific OA				
Talonavicular joint (TNJ), n (%)	0 (0)	118 (70)	0 (0)	35 (46)
Navicular-first cuneiform (NCJ), n (%)	0 (0)	36 (21)	0 (0)	48 (63)
First cuneiform-metatarsal (1st CMJ), n (%)	0 (0)	33 (19)	0 (0)	17 (22)
Second cuneiform-metatarsal (2nd CMJ), n (%)	0 (0)	0 (0)	103 (100)	76 (100)
Foot pain and functional limitation				
Foot pain severity in last month (0-10 NRS)	5.1 (4.9, 5.3)	5.5 (5.1, 5.9)	5.3 (4.8, 5.7)	5.8 (5.2, 6.3)
Duration of pain, %				
< 12 months	16.8 (13.3, 20.0)	9.9 (5.0, 14.8)	12.5 (5.9, 19.1)	3.0 (0.0, 7.2)
1 to < 5 years	37.0 (32.5, 41.5)	39.4 (31.4, 47.5)	34.4 (24.9, 43.9)	25.8 (15.2, 36.3)
5 to < 10 years	16.3 (12.9, 19.8)	21.8 (15.0, 28.6)	28.1 (19.1, 37.1)	34.8 (23.4, 46.3)
≥ 10 years	29.9 (25.7, 34.2)	28.9 (21.4, 36.3)	25.0 (16.3, 33.7)	36.4 (24.8, 48.0)
MFPDI Pain Score	-0.292 (-0.424, -0.160)	-0.299 (-0.529, -0.069)	0.136 (-0.133, 0.406)	0.183 (-0.164, 0.529)
MFPDI Function Score	-0.807 (-0.986, -0.628)	-0.553 (-0.862, -0.244)	-0.370 (-0.736, -0.004)	0.188 (-0.302, 0.678)

Table 1 continued. Person-level characteristics (age, sex, BMI, pain ratings, MFPDI) and foot-level characteristics for groups (n=879 feet)

	No or minimal foot OA (n=532)	**Medial midfoot OA (n=168)** TNJ or NCJ or 1st CMJ (and no 2nd CMJ)	**Central midfoot OA (n=103)** 2nd CMJ only	**Combined medial and central midfoot OA (n=76)** TNJ or NCJ or 1st CMJ & 2nd CMJ
Pain location and deformity				
Dorsal midfoot pain, %	23.3 (19.7, 26.9)	29.1 (22.3, 36.0)	30.0 (21.2, 39.0)	48.6 (37.4, 59.9)
Plantar midfoot pain, %	28.3 (24.6, 32.2)	26.1 (19.5, 32.8)	24.2 (16.0, 32.6)	13.1 (5.6, 20.8)
Midfoot bony exostosis, %	73 (68.8, 76.3)	60.7 (53.3, 68.1)	66.9 (57.9, 76.1)	59.2 (48.2, 70.3)
Hallux valgus, %	28.5 (24.7, 32.4)	33.9 (26.8, 41.1)	39.8 (30.4, 49.3)	48.6 (37.4, 59.9)
Concurrent 1st MTPJ OA, %	3.7 (2.1, 5.4)	23.8 (17.4, 30.3)	46.6 (37.0, 56.1)	34.2 (23.5, 44.9)
Foot posture				
Foot Posture Index	2.4 (2.3, 2.6)	2.1 (1.8, 2.4)	2.9 (2.6, 3.3)	3.2 (2.8, 3.5)
Supinated (<0), n (%)	40 (7.5)	16 (9.5)	5 (4.9)	1 (1.3)
Normal (0-5)	326 (61.3)	111 (66.1)	57 (55.3)	43 (56.6)
Pronated (≥6)	166 (31.2)	41 (24.4)	41 (39.8)	32 (42.1)
Arch Index	0.236 (0.231, 0.240)	0.242 (0.234, 0.249)	0.268 (0.258, 0.277)	0.272 (0.262, 0.283)
Low arch (<0.21), n (%)	331 (62.2)	109 (64.9)	55 (53.4)	46 (60.5)
Normal (0.21-0.28)	75 (14.1)	30 (17.9)	36 (35.0)	26 (34.2)
High arch (>0.28)	126 (23.7)	29 (17.3)	12 (11.7)	4 (5.3)
Navicular height	0.175 (0.173, 0.178)	0.176 (0.171, 0.180)	0.162 (0.156, 0.168)	0.151 (0.143, 0.159)
High (>0.18-0.29), n (%)	185 (34.9)	51 (30.5)	32 (31.1)	21 (27.6)
Normal (>0.16-0.18)	153 (28.9)	48 (28.7)	45 (43.7)	43 (56.6)
Low (0.06-0.16)	192 (36.2)	68 (40.7)	26 (25.2)	12 (15.8)

Joint range-of-motion				
Ankle joint dorsiflexion - knee extended, degrees[a]	62.4 (61.6, 63.2)	63.5 (62.2, 64.8)	63.1 (61.5, 64.8)	63.1 (61.4, 64.9)
Ankle joint dorsiflexion - knee flexed, degrees[a]	52.4 (51.6, 53.1)	54.4 (53.1, 55.7)	50.8 (49.2, 52.5)	54.9 (53.0, 56.8)
Subtalar inversion, degrees	27.4 (26.8, 28.1)	25.1 (24.0, 26.3)	27.7 (26.2, 29.2)	23.7 (21.8, 25.6)
Subtalar eversion, degrees	11.8 (11.3, 12.3)	10.8 (10.0, 11.7)	12.2 (11.1, 13.3)	11.9 (10.3, 13.4)
First MTPJ dorsiflexion, degrees	66.9 (65.4, 68.3)	63.2 (60.6, 65.8)	60.0 (56.3, 63.6)	59.4 (55.0, 63.8)

Values are presented as mean (95% CI) unless otherwise noted.

TNJ: talonavicular joint; NCJ: navicular-cuneiform joint; CMJ: cuneiform-metatarsal joint; OA: osteoarthritis; BMI: body mass index; MFPDI: Manchester Foot Pain & Disability Index; NRS: numerical rating scale; MTPJ: metatarsophalangeal joint

[a] Lower values indicate greater range of motion

Table 2. Relationship between midfoot OA groups and clinical foot and ankle characteristics (outcomes), adjusted for age, sex, BMI and presence of 1st MTPJ OA.

	Medial midfoot OA (n=168) TNJ or NCJ or 1st CMJ (& no 2nd CMJ)		**Central midfoot OA (n=103)** 2nd CMJ only		**Combined medial & central midfoot OA (n=76)** TNJ or NCJ or 1st CMJ & 2nd CMJ	
Foot pain and deformity	**Adjusted OR**	**95% CI**	**Adjusted OR**	**95% CI**	**Adjusted OR**	**95% CI**
Dorsal midfoot pain	1.54	1.02, 2.33	1.59	0.95, 2.66	2.54	1.45, 4.44
Plantar midfoot pain	0.95	0.69, 1.31	0.88	0.53, 1.45	0.63	0.37, 1.06
Midfoot bony exostosis	1.29	0.90, 1.85	1.14	0.69, 1.87	1.29	0.78, 2.15
Hallux valgus (Y/N)	1.18	0.79, 1.75	1.04	0.60, 1.80	1.76	1.02, 3.05
	Adjusted β	**95% CI**	**Adjusted β**	**95% CI**	**Adjusted β**	**95% CI**
Foot pain severity in last month	0.001	-0.001, 0.003	0.000	-0.002, 0.003	0.002	-0.001, 0.005
MFPDI Pain Score	0.000	-0.002, 0.003	0.004	0.0002, 0.008	0.004	0.0000002, 0.008
MFPDI Function Score	0.001	-0.001, 0.002	0.001	-0.001, 0.003	0.002	-0.0003, 0.005
Foot posture						
Foot Posture Index	-0.08	-0.33, -0.16	0.19	-0.12, 0.51	0.44	0.12, 0.77
Arch Index	0.005	-0.002, 0.01	0.01	0.000001, 0.02	0.02	0.01, 0.03
Navicular height	-0.002	-0.006, 0.003	-0.006	-0.01, 0.001	-0.01	-0.01, -0.00
Joint range-of-motion						
Ankle joint dorsiflexion - knee extended, degrees	0.59	-0.54, 1.74	-0.60	-2.12, 0.90	-1.00	-2.76, 0.75
Ankle joint dorsiflexion - knee flexed, degrees	1.11	-0.12, 2.35	-1.46	-2.92, -0.005	-0.54	-2.57, 1.49
Subtalar inversion, degrees	-1.71	-2.95, -0.47	0.51	-1.40, 2.42	-2.45	-4.41, -0.48
Subtalar eversion, degrees	-0.34	-1.35, 0.67	0.91	-0.56, 2.39	0.55	-1.02, 2.13
First MTPJ dorsiflexion, degrees	-1.71	-3.96, 0.54	-2.06	-5.10, 0.97	-4.30	-8.38, -0.21

Odds ratios (95% confidence intervals) are presented for binary outcome variables. Beta coefficients with 95% confidence intervals are presented for continuous variables. No or minimal midfoot OA is the reference category. Bold text indicates the result is considered statistically significant (odds ratio does not cross one or beta coefficient does not cross zero).

TNJ: talonavicular joint; NCJ: navicular-cuneiform joint; CMJ: cuneiform-metatarsal joint; OA: osteoarthritis; MFPDI: Manchester Foot Pain and Disability Index. MTPJ: metatarsophalangeal joint; CI: confidence interval